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First Bimonthly Report on the RT-21

Transmitter Development

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I. Purpose

The purpose of this program is to develop an electrical model meeting the RT-21 transmitter specifications as far as the state of the art permits. The specifications of the RT-21 transmitter represent a goal which cannot be attained at the present time. However, during the course of this eighteen-month program, it is anticipated that devices, particularly transistors, will become available, which will advance the state of the art, effectively bringing the goal considerably closer.

The main feature of the 3-30 mc 10 watt transistorized transmitter is the provision for automatic tuning and impedance matching. Ultimately, although not forming part of the present contract, the transmitter will be packaged in a highly miniaturized form. Because of this consideration, effort during the current contract will be restricted to techniques which will lend themselves to miniaturization and do not rely on inherently large components and devices.

In order to accomplish the automatic adjustment features, two approaches will be taken. The first will use servo motors and mechanically variable reactances. The second, which is a longer range approach, will not require moving parts, utilizing electrically variable reactances. The two systems will be studied in parallel. The transmitter, to be delivered at the conclusion of this program, will include the minimum number of moving parts as dictated by the progress of the second or solid state approach.

II. Abstract

During the first reporting period work has been concentrated on the overall system to be used in the RT-21 transmitter. Regardless of which method is used ultimately - mechanical or electrical - it is apparent that it will be necessary to provide sensing circuits to detect when the transmitter is tuned

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and when the antenna is matched. A study has consequently been made of appropriate sensing circuits. As an initial step in the development of electrically variable reactances, a sample of barium titanate with a voltage dependent dielectric constant has been prepared. This sample has not yet been evaluated. Studies have been made of commercially available junction diode capacitors and measurements made of diodes specially fabricated for this purpose.

An experimental oscillator has been built which uses voltage variable capacitors. Associated circuitry enables the resonant frequency to be increased until correct tuning is obtained for the particular crystal in use. The voltage is then maintained at whatever value the sweep voltage had reached when oscillation commenced.

III. Factual Data

1. Introduction

The RT-21 transmitter is to meet the following specifications, to the extent permitted by the state of the art.

Frequency Range 3-30 mc.

Output Power 10 watts

Antenna Impedances 25 - 1300 ohms $\pm$ j 1000.

Automatic Alignment

Automatic Impedance Matching

No vacuum tubes

Capable of extreme miniaturization

Crystal controlled CW transmission

Fundamental operation up to 15 mc. Second harmonic 15-30 mc.

While the present program calls for the construction of an electrical model, the design should be consistant with ultimate miniaturization to a volume of about

27 cubic inches (3" x 6" x 1-1/2").

2. System Considerations.

It is obvious that, at the present time, it is not possible to obtain 10 watts at 30 mc with transistors. Consequently, the planning of this program is arranged in such a way that the automatic features will be developed relatively independently of the transmitter output capabilities.

The transmitter proper is regarded as consisting of a crystal oscillator followed by an as yet undetermined number of stages of amplification. The automatic tuning is being developed on the premise that at a suitable point in the transmitter, a small portion of the RF voltage can be obtained, which can be used to control either an electrical or mechanical frequency sweep. Similarly, the automatic impedance matching system is being developed by assuming a transmitter output voltage and impedance level and designing sensing circuits which will indicate when this assumed impedance is matched to the range of antenna impedances specified. The output of the sensing circuits can be used to drive either mechanically or electrically variable reactances in the matching network.

3. Automatic Tuning

In a transmitter designed for simplified operation, such as the 3-30 mc transmitter designed during the Radio Circuit Study program, a multi-ganged tuning capacitor is used. As long as the Q of the tuned circuits is not extremely high, adequate tracking can be obtained. It follows, therefore, that in an automatically tuned transmitter satisfactory performance could be obtained if a single motor was used to drive one multi-gang capacitor or if one control voltage was used to vary a number of suitably tracked electrically variable capacitors. If only one control voltage is required, it can be obtained from the position in the transmitter where an indication of desired versus undesired conditions is most readily available.

A crystal oscillator can be designed in which no oscillation is obtained unless the tank circuit is tuned fairly closely to the correct frequency. A system has consequently been investigated with the following method of operation. For the solid state version, when the transmitter is switched on, with a crystal in place, a storage capacitor starts to charge. The voltage across the capacitor is used to bias the voltage variable capacitors in the tank circuit of the crystal oscillator. Initially, the voltage across the storage capacitor will be zero, the variable capacitors will consequently have their maximum capacitance. The resonant frequency of the tank circuit will be at a minimum. As the storage capacitor charges the resonant frequency will increase until it reaches a point at which oscillation commences. A portion of the oscillator output is rectified and used to turn on a transistor. The transistor gates off a modulator, the rectified output of which had been used to charge the storage capacitor. The voltage across the storage capacitor ceases to increase and the frequency sweep is arrested at the correct frequency for the crystal in use. The storage capacitor is associated with a high impedance circuit so that the charge leaks away quite slowly. As it does, however, the oscillator output starts to fall slightly. The transistor switch starts to turn off, permitting the modulator to give a small output which, when rectified, replaces the charge which had leaked from the storage capacitor. The oscillator tuned circuit is consequently kept very close to the correct frequency at all times.

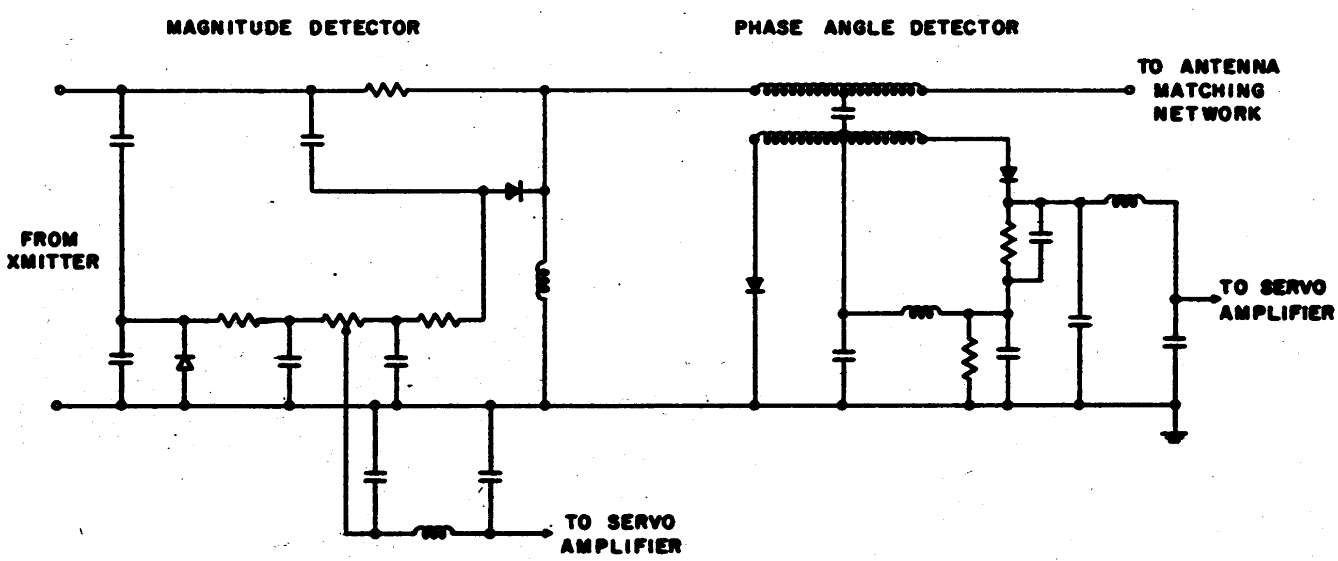
When the crystal is removed from the socket, a micro switch shorts out the storage capacitor, so that, on inserting a different crystal, sweeping can commence from the lowest frequency. This is important as it insures that between 3 and 15 mc, the charging voltage is only able to adjust the tuned circuit to the fundamental frequency rather than locking in on a harmonic. Between 15 and 30 mc, the first response will be at the second harmonic whereupon the sweeping action will stop.

With the mechanical system, the operation would be similar except that in place of the modulator would be a switch controlling a servo motor. The motor would turn a multi-gang tuning capacitor until an output was obtained at which point the switch would open, stopping the motor. A mechanical system of this type has an inherent memory which eliminates the need for subsequent adjustments to keep the circuits on frequency. Removal of the crystal operates a micro switch which returns the motor to the maximum capacitance, minimum frequency position.

4. Automatic Impedance Matching

Regardless of the degree of success of the all electronic approach, sensing circuits will be required to determine when the antenna is tuned and matched to the transmitter. It will be necessary to sense both the amplitude and the phase of the signal fed to the antenna. This can be done by use of circuits of the type shown in Fig. 1. The outputs from the phase and amplitude detectors are fed to two amplifiers, the output from which control either motors driving variable reactances, or electrically variable components. The amount of gain required in the servo amplifiers is related to the fraction of transmitter output sacrificed for control purposes and the actual output level. Consequently, as the power handling capabilities of transistors increases, the amount of gain in the servo amplifiers can be reduced.

The major difficulty which is anticipated in the automatic impedance matching program is that of realizing reactances with the necessary maximum to minimum ratios whether a mechanical or electrical component is visualized. The required antenna impedance range from 3-30 mc of 25-1300 ohms $\pm$ j 1000 calls for a maximum to minimum ratio of about 1000.1. Furthermore, the extremes of the range require impractically small or large values of inductance or capacitance. It appears necessary to introduce added circuit complexity in order to



AMPLITUDE AND PHASE SENSING CIRCUITS

FIGURE 1

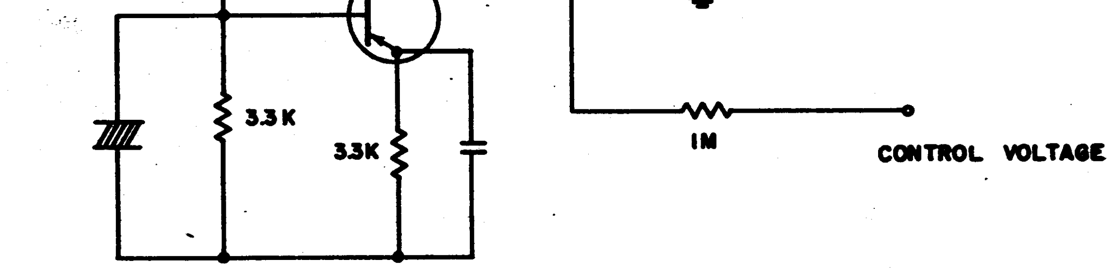
achieve the desired results. A study has been initiated in order to determine an optimum system which calls for realizable reactances.

5. Voltage Tuned Oscillator

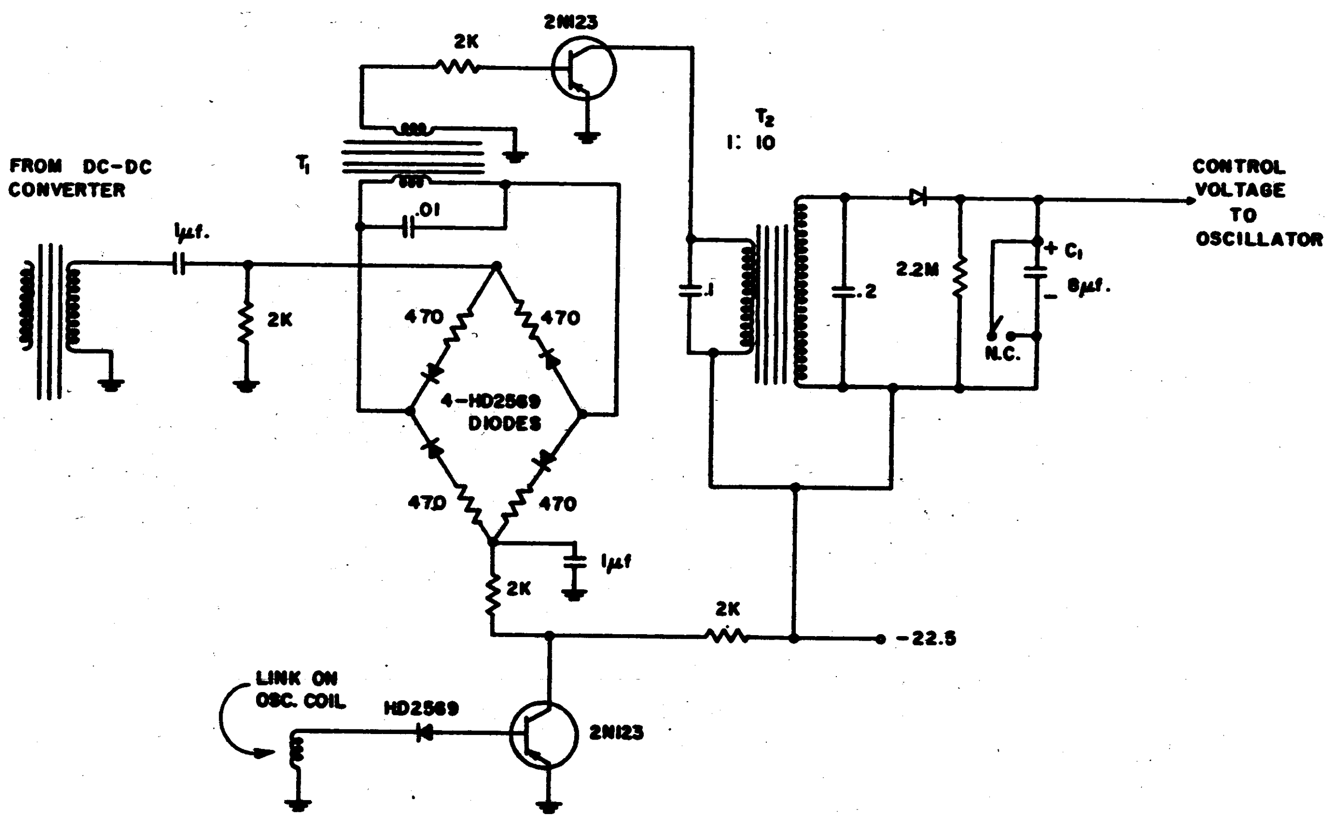
The oscillator shown in Fig. 2 has been designed so that there is no output unless the tank circuit is quite closely tuned to the correct frequency for the crystal in use. By placing the voltage controlled diodes in a back-to-back configuration as shown, a reduction in capacitance range due to self bias, is avoided. The tank inductance has been chosen so that the oscillator may be operated at any frequency from 3-15 mc by appropriate choice of capacitance. To prevent spurious responses, it is necessary to change the value of the emitter bypass capacitor over the 3-15 mc range. A few steps seem adequate and the necessary switching can probably be achieved using breakdown diodes. This problem has not yet been studied in detail. The solution appears to be closely linked with the switching which, in all probability, will be necessary in order to obtain a sufficient range of capacitance across the tank circuit.

6. Tuning Control Circuitry

In order to vary the resonant frequency of the oscillator tank circuit a D.C. sweep voltage is required. This is obtained from the rectified modulator output as shown in Fig. 3. The imput to the modulator in the complete transmitter would come from the DC to DC converter. In the present tests an audio generator is being used. Under initial conditions, with the power on and the crystal in place, the bridge modulator is unbalanced, so that an output appears on the secondary of T_1. A single stage of amplification is provided, the output appearing across T_2. The rectified output charges the storage capacitor C_1. When the correct frequency is reached and oscillation commences, a portion of the driver stage output is rectified and used to balance the modulator



CRYSTAL OSCILATOR CIRCUIT
FIGURE 2



BALANCED MODULATOR SWITCH PRODUCING
OSCILLATOR CONTROL VOLTAGE.

FIGURE 3

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terminating the sweep voltage, which is stored on C_1. As the charge slowly leaks away, the modulator becomes slightly unbalanced allowing the charge to be replenished.

7. Voltage Variable Capacitors

For the purpose of testing and evaluation, a sample of barium titanate, the dielectric constant of which is a function of applied voltage, has been prepared. At the conclusion of the present report period, time had not permitted the electroding and measurement of the sample but it is anticipated that it will possess characteristics similar to those shown in Fig. 4.

It may be observed that the region of greatest variation of dielectric constant is in the neighborhood of the Curie temperature. Ultimately, the transmitter is to operate over a temperature range from -40° C to $+40^\circ$ C. In order to accommodate this range, a possible solution may be found in fabricating capacitors from several barium titanate materials, each with its Curie temperature at a different point. These capacitors may then be placed in parallel. The material with its Curie temperature closest to the prevailing ambient will provide the predominant capacitance since the dielectric constant will be higher than that of the other materials. Naturally the maximum to minimum ratio will be reduced as capacitors are placed in parallel. Whether this reduction in range will be too great will be determined in subsequent experiments.

Commercially available diodes for use as voltage variable capacitors suffer from two undesirable characteristics. The first is a somewhat limited maximum to minimum capacitance ratio. The second is the Q, particularly at the high capacitance end of the range. During the present report period an experimental diode was made in an attempt to improve on the commercially available types. The measurements are given in Fig. 5. The results are not particularly impressive although published curves of commercial diodes are frequently deceptive

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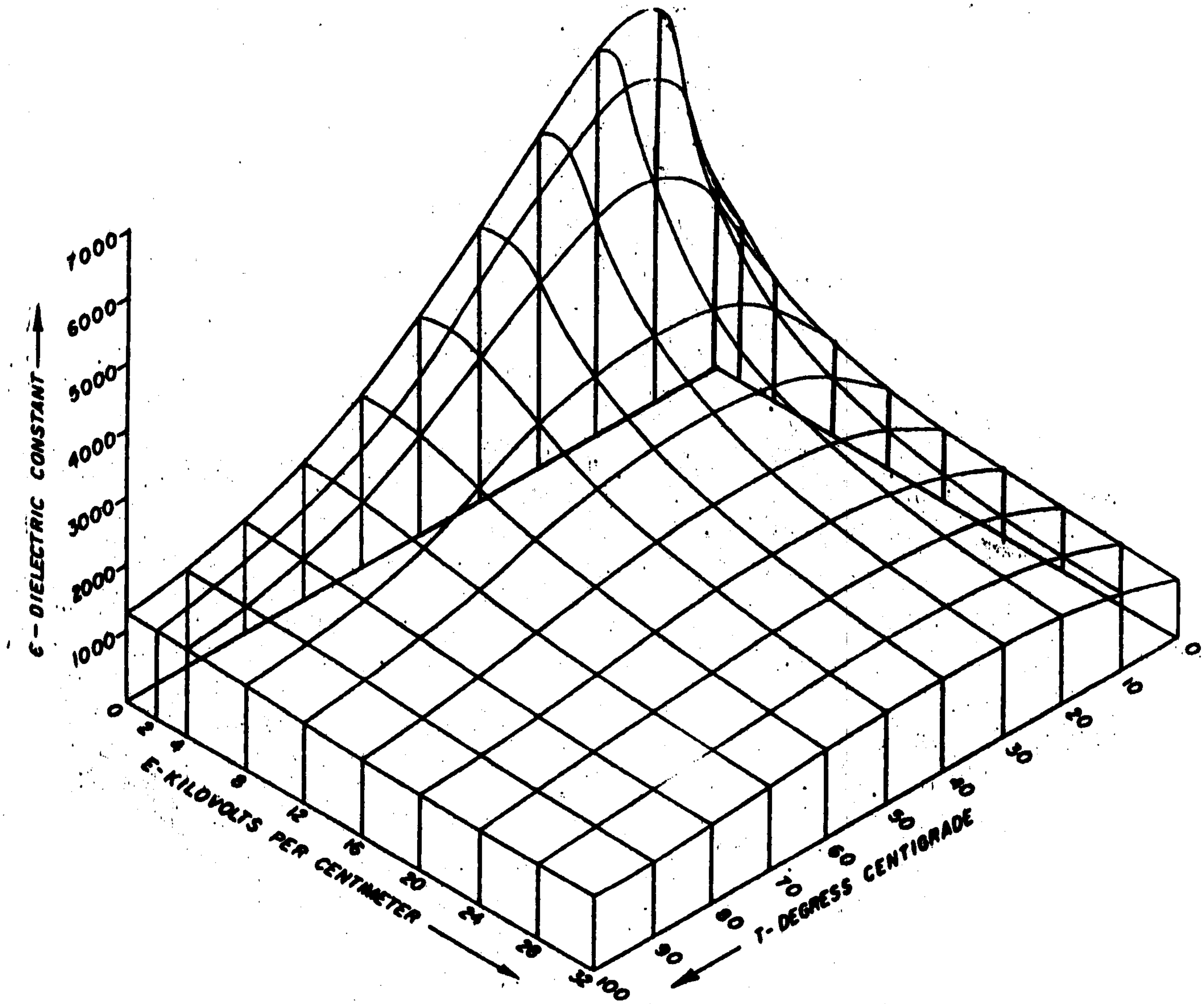

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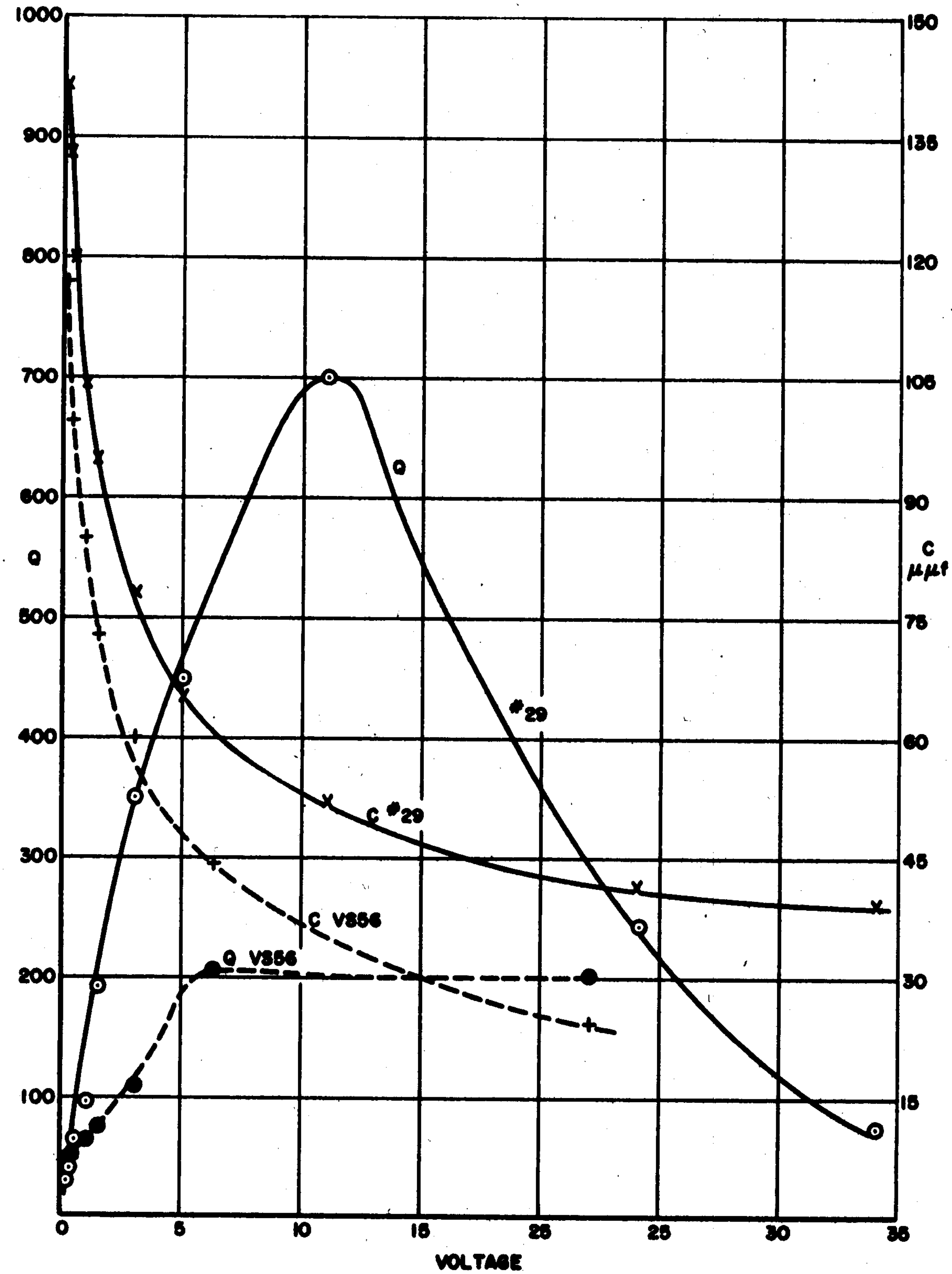
FIGURE 4



CAPACITANCE & Q AS A FUNCTION OF BIAS VOLTAGE FOR EXPERIMENTAL DIODE NO 29 AND PACIFIC SEMICONDUCTOR VS56

FIGURE 5

and tend to show the device to advantage. A maximum to minimum ratio is quoted on the basis of a bias of as low as 0.1 volts. However, the curves for Q are rarely shown for values below about 10 to 15 volts, thereby omitting the range in which the capacitance change is greatest and the Q poorest.

IV. Conclusions

At this early stage of the program it is not intended to draw far-reaching conclusions. Various approaches are being and will be taken and evaluated. At the present time the experimental work which has been carried out has shown the practicality of using the presence or absence of output from the crystal oscillator as the frequency sensing indication. This method is appropriate for either mechanical or electrical variation of tuning elements. As mentioned in the body of the report, an investigation will have to be made to determine a simple way in which to change the value of the emitter bypass capacitor. Similarly, a simple automatic switching system will have to be developed as it is unlikely that an electrically variable reactance with a range of 25-1 will be available to tune from 3-15 mc. The upper range, from 15-30 mc does not appear to present too great a problem.

Calculations of the antenna matching network have shown that for a straightforward two element system reactances with an impractically large range of variation are required. Efforts are being directed towards a system which can be built with realizable components and a minimum of additional circuit complexity. Since it will be necessary for the operator to indicate his decision concerning whether he desires to operate on the fundamental or the second harmonic, the 3-30 mc range will have to be divided into two bands, crystals with fundamental frequencies above 15 mc not being admissable. Methods of capitalizing on this compulsory division of the range into two bands are being investigated.

V. Future Plans

Work during the next period will be divided into two areas. The first will be concerned with the investigation of, as yet, untried methods of sensing and control and the other will be devoted to a study of the problems which have appeared as a result of the work which has already been done.

In the former area, a study of phase and amplitude sensing circuits will be made, assuming a reasonable output level is available from the transmitter. From work done during the present period, the following problems arise. As mentioned in the body of the report, a method of automatic switching is needed which will enable a change in capacitance of 25:1 to be obtained with components which individually are capable of a considerably more limited range. Associated with this problem is that of switching the oscillator emitter bypass capacitor.

During the present period samples of barium titanate have been prepared. Measurements will be made to determine the degree to which the dielectric constant is a function of the applied bias voltage. It is anticipated that the temperature range over which appreciable variation can be obtained will be fairly limited. However, by combining in parallel capacitors fabricated from materials with different Curie temperatures, it is expected that it will be possible to extend the temperature range appreciably. This method has the disadvantage of reducing the range of variation at temperatures in the vicinity of the individual Curie temperatures.

VI. Bibliography

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